Composing Sea Ice Stanzas

Climate scientist **Elizabeth Hunke** reflects on ice, music, and 25 years at Los Alamos.

I THOUGHT I WOULD BE A MUSICIAN.

I am, actually, a musician—I've played piano and brass instruments since I was in grade school. In high school I pursued music, science, and math somewhat equally, but after my first year of college I realized that if I majored in music it would become work, and my enjoyment of it might fizzle. Also, it would probably be more tenable to make a living doing math or science, keeping music as a hobby, than vice versa. So, I chose math.

I love the elegance of mathematics and its applications—it is a natural companion to both music and science. It also seemed like a reliable avenue into just about any scientific enterprise, so I could keep my interests diverse. I started my scientific career as an intern at AT&T Bell Laboratories working in molecular beam epitaxy, analyzing a molecular structure simulation for its potential electrical properties. I've since studied tornadoes and hurricanes, sea ice, and even the wildlife that lives on (or in) the ice. I continue to enjoy playing music with a handful of local ensembles, while building a career in science that has been varied, challenging, rewarding, and enormously fun. Throughout my career in climate science at Los Alamos, I've often appreciated the parallels and overlap between being a musician and being a scientist.

Melting sea ice affects how ocean water circulates. Here, Los Alamos climate scientist Elizabeth Hunke—wearing an heirloom parka made by her mother, who was an early and staunch supporter of Hunke's scientific, artistic, and adventurous pursuits—demonstrates the difference in how ice (with blue dye) melts into salt water (left) compared to fresh water (right). When sea water freezes to form sea ice, most of the salt drains into the water below. So when that ice melts, it forms a lightweight layer of fresher meltwater atop the salty seawater (left), capping the ocean and suppressing vertical, convective circulation. *PHOTO CREDIT: Michael Pierce*

Playing with a musical group can be deeply satisfying, as the musicians' independent sensibilities meet and meld to create something new and beautiful from essentially nothing. Just as staves of music notes describe rolling arpeggios of sound, stacks of mathematical formulae describe elaborate processes occurring in nature. Computers are our "instruments" in the modeling world, and while not everyone would consider a computer program beautiful, the complexity and elegance of mathematical modeling is, to me at least, both beautiful and satisfying.

From the tropics to the poles

Designing a mathematical model for a particular scientific phenomenon and then writing a computer program to solve it is, like making music, a creative process. It's also tremendously complicated for climate applications. Weather forecasting provides a good, everyday example of these kinds of models at work. A weather model combines data on changing temperatures, humidity, pressures, and wind, across different altitudes and through time, with a complex set of mathematical equations to make a prognostication about what is most likely to happen in the near future.

Designing a mathematical model for a scientific phenomenon and writing a computer program to solve it are both creative processes.

I came to Los Alamos 25 years ago, fresh out of graduate school, to join the ocean modeling team in the Theoretical Division. I had done my doctoral work on tropical cyclone modeling, having had my interest piqued by a professor who presented a simple mathematical model describing how hurricanes work. As with my early ideas of making a career in music, I thought hurricane modeling would be my life's work, and I hoped for the opportunity to fly into a hurricane aboard a research aircraft. But, although that opportunity never came, and although I could not have dreamed it at the time, I have since traveled to the ends of the earth doing polar research.

In graduate school, I spent a summer as an intern at Los Alamos, and my mentor from that time, Mac Hyman, remained a mentor throughout graduate school and indeed my whole career. When I began looking for a postdoctoral job, climate change was becoming a hot topic and Mac steered me toward it. The ocean modeling team wanted to develop a computationally efficient sea ice model that would be compatible with the Parallel Ocean Program, an ocean circulation model developed at Los Alamos in the early 1990s. The goal was to eventually create a fully coupled atmosphere-ice-ocean-land global climate model that would efficiently utilize the computational power offered by the new, massively parallel supercomputers becoming available at that time, using thousands of processors at once to solve intricate sets of mathematical equations.

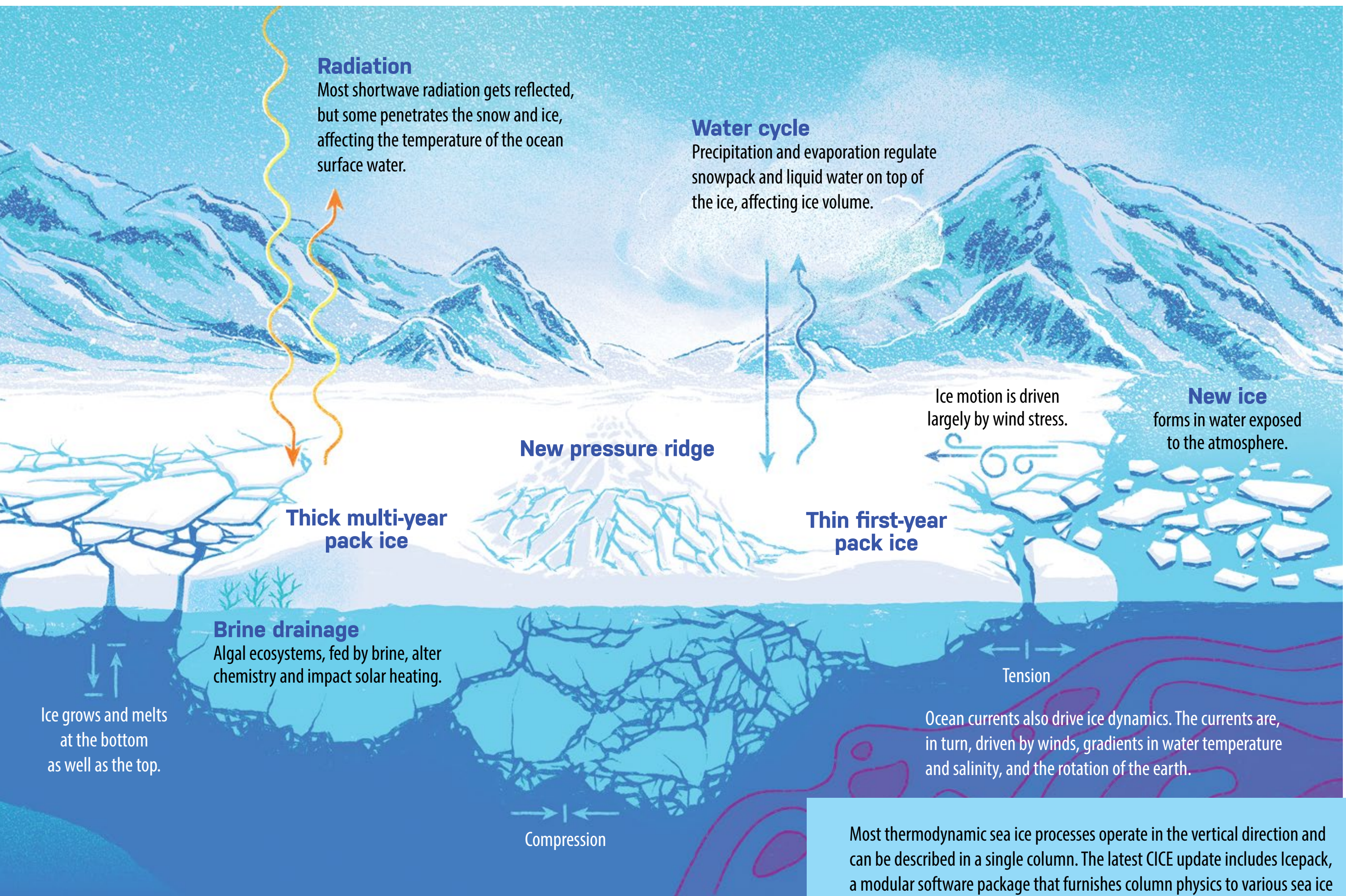
Rapidly declining Arctic sea ice means more ships are attempting to get through, so the safety and economic stakes are ever higher. CICE predicts sea ice extent, thickness, and movement around polar oceans using data from atmosphere and ocean systems, in turn collected by buoys, ships, aircraft, and satellites. The latest update to CICE improves modeling of landfast ice, ice that is anchored to the shore or sea floor. Landfast ice can block shipping lanes and ports, even when the rest of the route is passable. Having an idea of when ice will form, melt, or drift out to sea helps mariners and coastal communities plan their activities wisely.

Sea ice and hurricanes seem like very different phenomena, but the equations used to describe them are actually quite similar, and it wasn't a huge leap for me to move into sea ice modeling. As I had anticipated, the mathematical knowledge and skills that I developed in graduate school translated easily to my new job as a sea ice modeler.

The impact of weather on humans has always been of interest to me. I spent some time as a child in Cordova, Alaska, with my father who was a Coast Guard officer in Prince Edward Sound. Even in elementary school, I was aware that the huge snowstorms in Cordova were a result of warm ocean currents bringing moisture to that area. Little did I know then how large a role the sea ice I saw in the harbor would play in my later life! I come from a family of Tennessee farmers, where the weather, again, is never far from our minds, having the power to make or break each year's crop. My mother, having been fascinated by crop dusters when she was growing up, became a pilot about the time I started kindergarten. I'm now a private pilot too, as well as an avid gardener; both pursuits are rooted in my farming background and demand close attention to the weather.

CICE for sea ice

About nine million square miles of sea ice float on top of the world's high-latitude seas and oceans. Sea ice helps keep polar regions cool. It is constantly in motion and constantly changing internally. It influences Earth's climate, wildlife, and people who must contend with it year-round. Sea ice makes navigation difficult, creating challenges for commercial shipping, mining and energy development, fishing, hunting, tourism, scientific research, military bases, and defense operations.



Most thermodynamic sea ice processes operate in the vertical direction and can be described in a single column. The latest CICE update includes Icepack, a modular software package that furnishes column physics to various sea ice models with different horizontal structures. Icepack provides the sea ice modeling community with insights into thermodynamics, biogeochemistry, and mechanical ridging, as well as changes in ice area and thickness.

When sea water freezes into sea ice, most of the salt drains into the water below it. Now denser from all that salt, that water sinks deeper into the ocean, and migrates toward the equator while warmer equatorial waters circulate into the polar regions. Under the influence of wind and ocean currents, the relatively fresh ice moves to other locations on the ocean surface, and as it melts it suppresses convection and vertical motion in the ocean with a lightweight layer of fresher meltwater. In this way, changes in the evolution of sea ice can modify the global "conveyor belt" of heat moving through the world's oceans. Another way that sea ice alters the earth's heat is through its reflectivity—pure white ice reflects much more solar radiation than dark, open seawater, which absorbs it.

Arctic communities, whether indigenous or commercial—and whether human or walrus, for that matter—care a great deal about where the sea ice is. But the most important thing to understand in order to model the physical system is where the ice is not. The open water between ice floes largely controls fluxes of energy, moisture, and momentum between the atmosphere and ocean, and the snow and ponds on top of the ice are crucial for sea ice evolution.

I am the principal developer of CICE, the Los Alamos sea ice model, which models the sea ice environment. CICE incorporates physical effects of the atmosphere and ocean on the ice, and allows physical feedback mechanisms between them and the sea ice to function in Earth system models. I now lead the CICE Consortium, an international group of institutions jointly developing and maintaining CICE in the public domain for research and operational communities. Originally, CICE was pronounced "sea ice" (it is not an acronym), but although that pronunciation was both fun and appropriate, it created confusion in conversation—do you mean actual sea ice, or the model, CICE?

Elizabeth Hunke with a simulation of sea ice thickness in the Arctic. The image was produced by the Los Alamos sea ice model, CICE, which Hunke has spent her career developing, as part of the Department of Energy's new flagship Energy Exascale Earth System Modeling (E3SM) effort. Her work promotes a better understanding of how sea ice responds to and helps modulate the global climate.
PHOTO CREDIT: Michael Pierce

So the Consortium decided to clear things up and amend the pronunciation to "Sice." Less fun, but more clear.

When I came to Los Alamos in 1994 as a postdoc, my first task on the ocean modeling team was to rewrite a 1970s-era sea ice thermodynamics model to run on supercomputers. When the team began working on the ice dynamics, we encountered a numerical challenge: the standard mathematical equations for sea ice stress "blow up," or become mathematically infinite, in a perfectly physical situation, when the ice is not moving. My colleague and mentor, John Dukowicz, solved two problems at once by introducing a clever numerical remedy, which prevented the stress equations from blowing up and also allowed the numerical algorithm to parallelize beautifully. That work became the core of CICE.

Changes in sea ice melting and freezing can alter the global "conveyor belt" of heat.

CICE 1.0 was rolled out in 1998, and our first community users were the Naval Postgraduate School and, soon thereafter, the National Center for Atmospheric Research (NCAR). Since then, numerous entities around the world have joined the CICE community, both using and contributing to the model. Several institutions use the model for operational forecasting on short time scales, including the U.S. Navy and the U.K. Met Office. Numerical weather-prediction products from the U.S. National Centers for Environmental Prediction use the dynamics component of CICE. Numerous institutions, including the U.K. Met Office and NCAR, use the CICE model for long-term climate simulations.

CICE was originally developed for global climate studies using highly parallel computing systems, and it's now also used for smaller scale, higher resolution studies of regional climate processes. The model solves a collection of mathematical equations that represent the physical processes that occur during sea ice evolution: growth, melting, and movement, along with snow and liquid water carried along with the ice.

In 2018, CICE 6.0 was released with two major new capabilities. First, as numerical approaches for solving the sea ice model equations have diversified across various modeling institutions, separating the sea ice column physics from the main CICE model became desirable. From the original CICE code we created an independent software package, Icepack, which specifically models the column physics, or those phenomena that can be described in a single vertical column. Icepack encompasses most sea ice physics, including biogeochemistry, radiation physics, hydrology, thermodynamics, and mechanical deformation that results in ridges within the pack ice. Icepack opens fresh opportunities for using CICE's extensive sea ice physical parameterizations in other sea ice models and for single-column applications. Second, our Canadian colleagues contributed the ability to model landfast ice in CICE. This is sea ice that is attached to coastlines or the sea floor and directly affects the length of shipping, hunting, and fishing seasons. Landfast ice can block river channels too, causing floods during spring runoff.

CICE was a part of the initial version of the Department of Energy's new flagship Energy Exascale Earth System Modeling effort, called E3SM. This is a comprehensive Earth system modeling and simulation project to investigate the most critical, energy-relevant scientific questions. The latest version of E3SM uses a new sea ice model called MPAS-seaice, which was developed by the Los Alamos sea ice modeling team. The new model includes CICE's Icepack software for the sea ice column physics and applies advanced new technologies for other aspects.

CICE continues to be used by many modeling centers, and collaboration is at the heart of its success. CICE is continually being improved, updated, and otherwise modified via dynamic collaborations within the broader sea ice modeling community. My role now is largely to coordinate these efforts, and my hope is that together we will enable an even better understanding of how sea ice keeps the polar regions cool and helps modulate the global climate.

Beyond the sea

I've traveled, literally from one end of the earth to the other, and I still go to the field when the opportunity arises, but truthfully my research has always been done mostly on computers. As the lead developer of CICE, I am ultimately responsible for model development, incorporation of new parameterizations, model testing and validation, computational performance, documentation, and consultation with external model users on all aspects of sea ice modeling, including interfacing with global climate and Earth systems models. Thankfully, I've had a lot of help.

I feel fortunate to have quickly found my niche doing Earth system modeling at the Laboratory. But this was not pure luck—I have had the support of many mentors and peers at all stages of my technical career. I subscribe to the belief that everyone should always have, and always be, a mentor. My mother was my first mentor. She became a private pilot when I was little, supported me in my diverse interests, and modeled courage and integrity every day. When we lived in Alaska, she sewed matching parkas for us, and I still have hers. I also had excellent mentors throughout high school, college, and graduate school—both men and women. It was hard to overcome the intimidation of being the only girl in physics class, to eventually become a self-confident woman in a traditionally male-dominated scientific field. My first trip to a polar region was to Antarctica, to take samples and measurements of real sea ice, with one of the field's most eminent scientists, Steve Ackley. The experience provided a critical boost for me as a young scientist, requiring courage and generating confidence in my own expertise.

The most rewarding aspect of my work at Los Alamos has not been my research, per se, but the fostering of collaboration among other scientists, including students, postdocs, and experts from disciplines outside of high-latitude climate. I'm at least 50 percent manager now, and I'm happy to have spent much of my career making connections among people, which has enabled a lot of great science. I'm now a senior scientist and deputy group leader of the T-3 Fluid Dynamics and Solid Mechanics Group at Los Alamos and a Program Manager for the Laboratory's Biological and Environmental Research programs within the Department of Energy's Office of Science. I represented the United States as a member of the International Arctic Science Committee for the past eight years and was a contributing author for the Intergovernmental Panel on Climate Change Fourth and Fifth Assessment Reports. Recently, I was honored as a Rothschild Fellow of the Isaac Newton Institute for Mathematical Science at the University of Cambridge, U.K., a true honor for a vicarious mathematician.

Collaboration within the sea ice modeling community lies at the heart of CICE's success.

I am a strong proponent of diversity in the workplace. My mentor at Bell Laboratories, Dr. Julia Phillips (now retired from Sandia National Laboratories), had a tremendous influence on my life. Now I encourage girls to consider technical careers when I run STEM workshops. As deputy group leader, I initiated an outreach program in which staff members provide hands-on workshops in Northern New Mexican elementary school classrooms. As a member of the international female pilot organization The Ninety-Nines, I volunteer to take interested girls up in my Piper Cherokee, so they can experience the thrill and empowerment of flying.

As a global community we have to look to the future, mitigate some symptoms and otherwise adapt to the impact of a changing climate. In order to do that, we will have to understand what is happening and why. My work in sea ice modeling is a small contribution to this worldwide, vital effort. I feel a deep sense of sorrow for the state of the earth we are handing to future generations, and yet I feel enormous hope and confidence in them to find beautiful and creative solutions. I encourage young people not just to choose technical careers, but to choose fulfilling and self-sustaining careers, whether they are in STEM fields or not. We can't all be scientists, engineers, and pilots. The world needs musicians too. LDRD

—Elizabeth Hunke